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Asakura et al.

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(54) **DATA ANALYSIS METHOD FOR PLASMA PROCESSING APPARATUS, PLASMA PROCESSING METHOD AND PLASMA PROCESSING APPARATUS**

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H01L 21/306	(2006.01)
H01J 37/32	(2006.01)

(52) **U.S. Cl.**

CPC ***H01J 37/32926*** (2013.01); ***H01J 37/32009*** (2013.01); ***H01J 37/32972*** (2013.01); *H01J 2237/334* (2013.01)

(58) **Field of Classification Search**

CPC H01J 37/32926; H01J 37/32009; G01J 3/443

USPC 156/345.24

See application file for complete search history.

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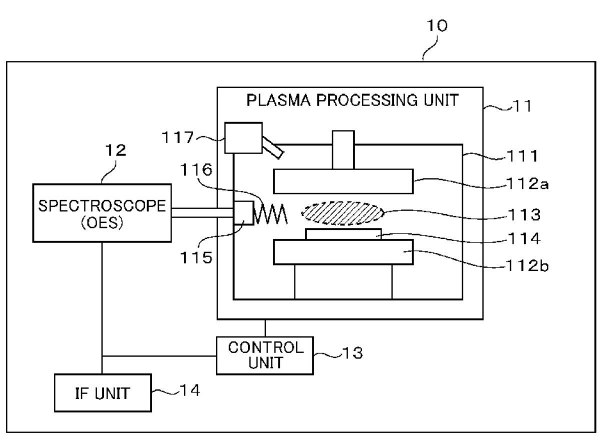
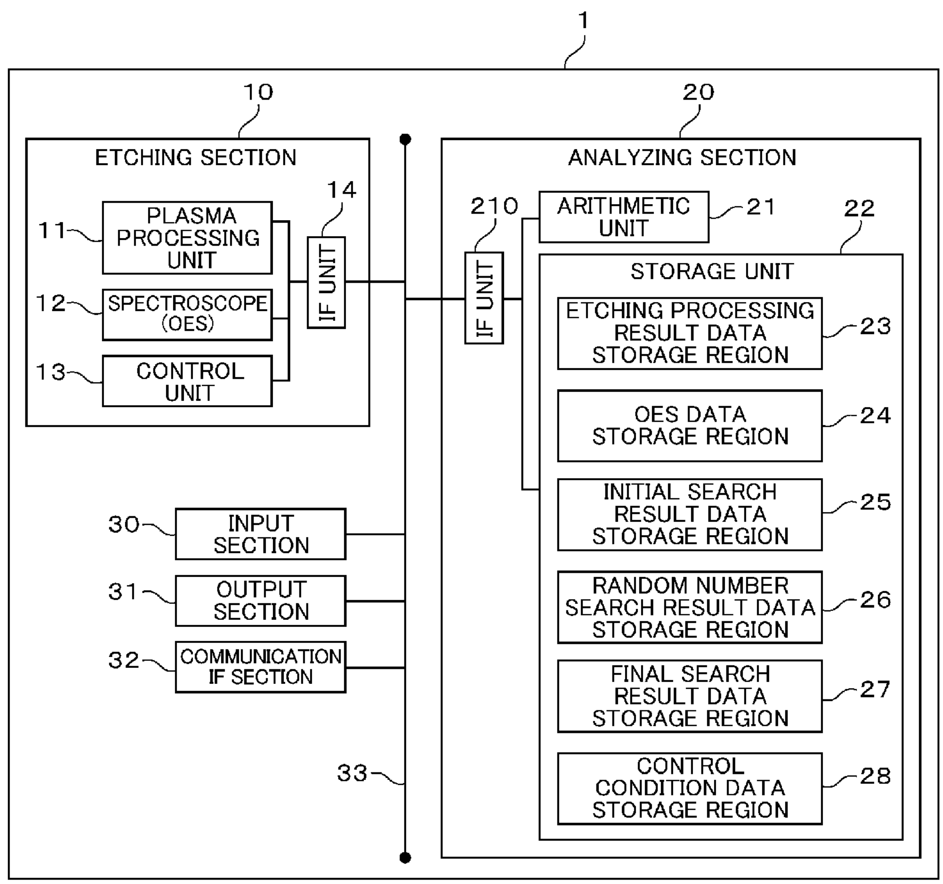
(57) **ABSTRACT**

A stable etching process is realized at an earlier stage by specifying the combination of wavelength and time interval, which exhibits a minimum prediction error of etching processing result within a short period. For this, the combination of wavelength and time interval is generated from wavelength band of plasma emission generated upon etching of the specimen, the prediction error upon prediction of etching process result is calculated with respect to each combination of wavelength and time interval, the wavelength combination is specified based on the calculated prediction error, the prediction error is further calculated by changing the time interval with respect to the specified wavelength combination, and the combination of wavelength and time interval, which exhibits the minimum value of calculated prediction error is selected as the wavelength and the time interval used for predicting the etching processing process.

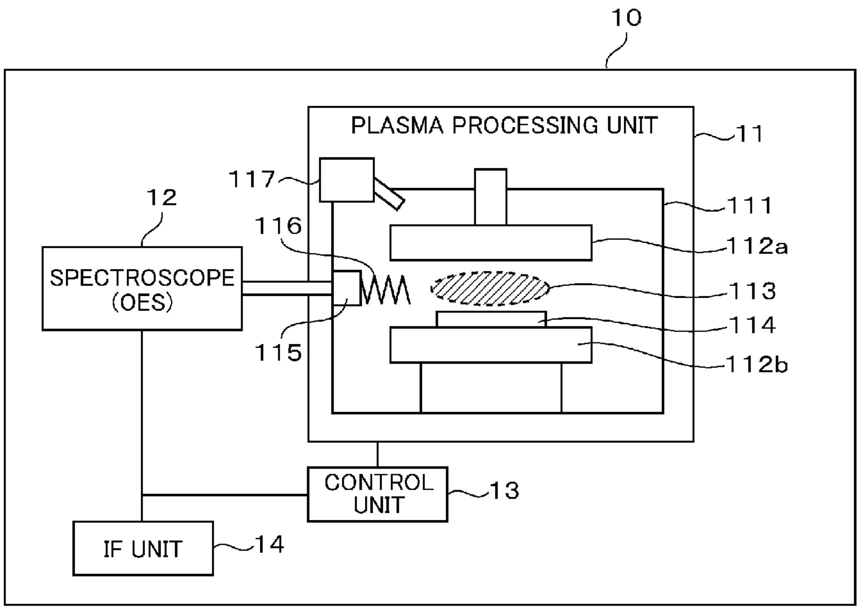
3 Claims, 12 Drawing Sheets



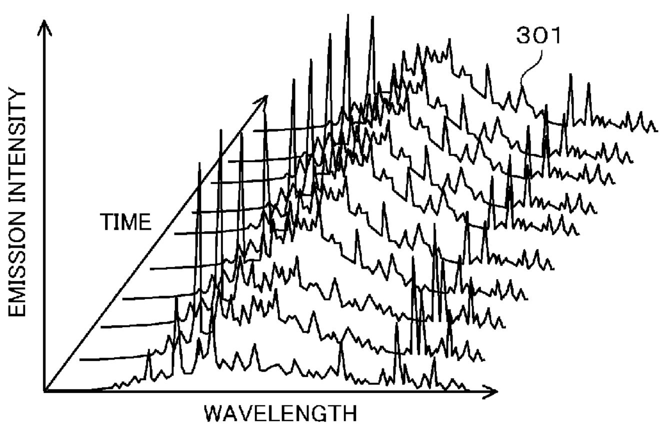
F I G. 1


1
10
ETCHING SECTION
14
11
PLASMA PROCESSING UNIT
12
SPECTROSCOPE (OES)
13
CONTROL UNIT
IF UNIT
20
ANALYZING SECTION
210
ARITHMETIC UNIT
21
22
IF UNIT
STORAGE UNIT
ETCHING PROCESSING RESULT DATA STORAGE REGION
23
OES DATA STORAGE REGION
24
INITIAL SEARCH RESULT DATA STORAGE REGION
25
RANDOM NUMBER SEARCH RESULT DATA STORAGE REGION
26
FINAL SEARCH RESULT DATA STORAGE REGION
27
CONTROL CONDITION DATA STORAGE REGION
28
30
INPUT SECTION
31
OUTPUT SECTION
32
COMMUNICATION IF SECTION
33

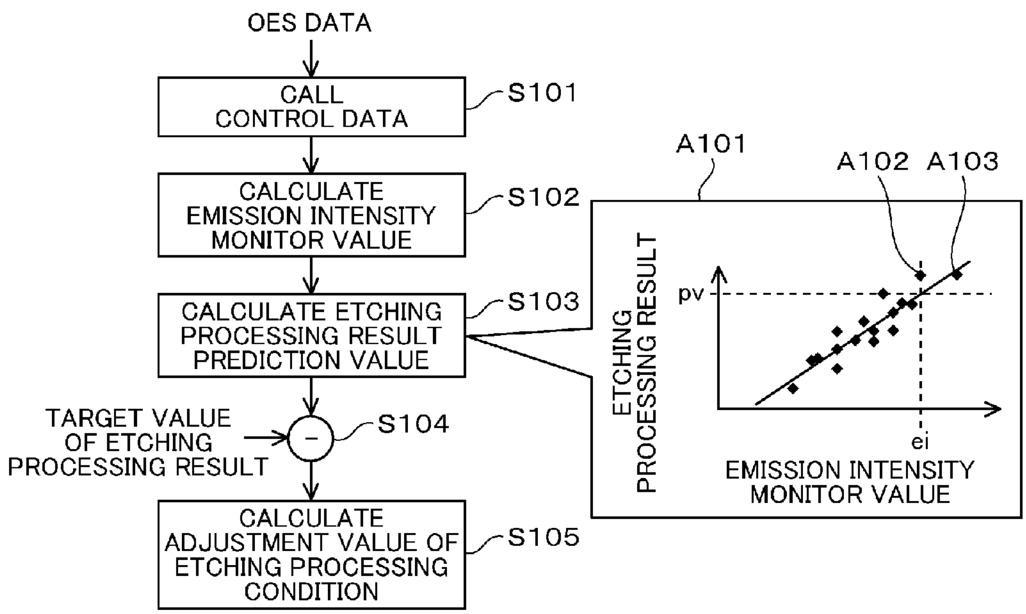
F I G. 2


10
PLASMA PROCESSING UNIT
11
117
111
12
116
112a
SPECTROSCOPE (OES)
113
114
115
112b
CONTROL UNIT
13
IF UNIT
14

F I G. 3


301
EMISSION INTENSITY
TIME
WAVELENGTH

F I G. 4



F I G. 5

23a

23b	WAVER ID	p1	p2	· · ·	p100
23c	ETCHING PROCESSING RESULT	0.75	0.80	· · ·	0.71

F I G. 6

24a

24b

WAVER ID		p1			
		WAVELENGTH			
		201	202	···	800
TIME	1	103	103	···	77
	2	107	108	···	82
	···	···	···	···	···
	100	140	142	···	96

24c

24e

24d

F I G. 7

25a

25b 25c 25d 25e 25f 25g 25h 25i 25j 25k 25l

ID	WAVELENGTH 1	WAVELENGTH 2	WAVELENGTH 1-TIME INTERVAL	WAVELENGTH 2-TIME INTERVAL	PREDICTION ERROR	PREDICTION ERROR RANK	CONTINUOUS SEARCH	TANDARD DEVIATION OF EMISSIONINTENSITY	PREDICTION ERRORRANK 1 (GROUP OF SMALL STANDARD DEVIATION)	PREDICTION ERROR RANK 2 (GROUP OF LARGE STANDARD DEVIATION)
1	251	288	1-50	1-100	0.124	465	-	21	129	-
2	451	656	1-50	1-100	0.089	116	-	32	72	-
···	···	···	···	···	···	···	···	···	···	···
1000	251	772	51-100	1-100	0.021	2	○	129	-	2
···	···	···	···	···	···	···	···	···	···	···
1200	288	772	51-100	1-100	0.019	1	○	108	-	1
···	···	···	···	···	···	···	···	···	···	···

FIG. 8

26a

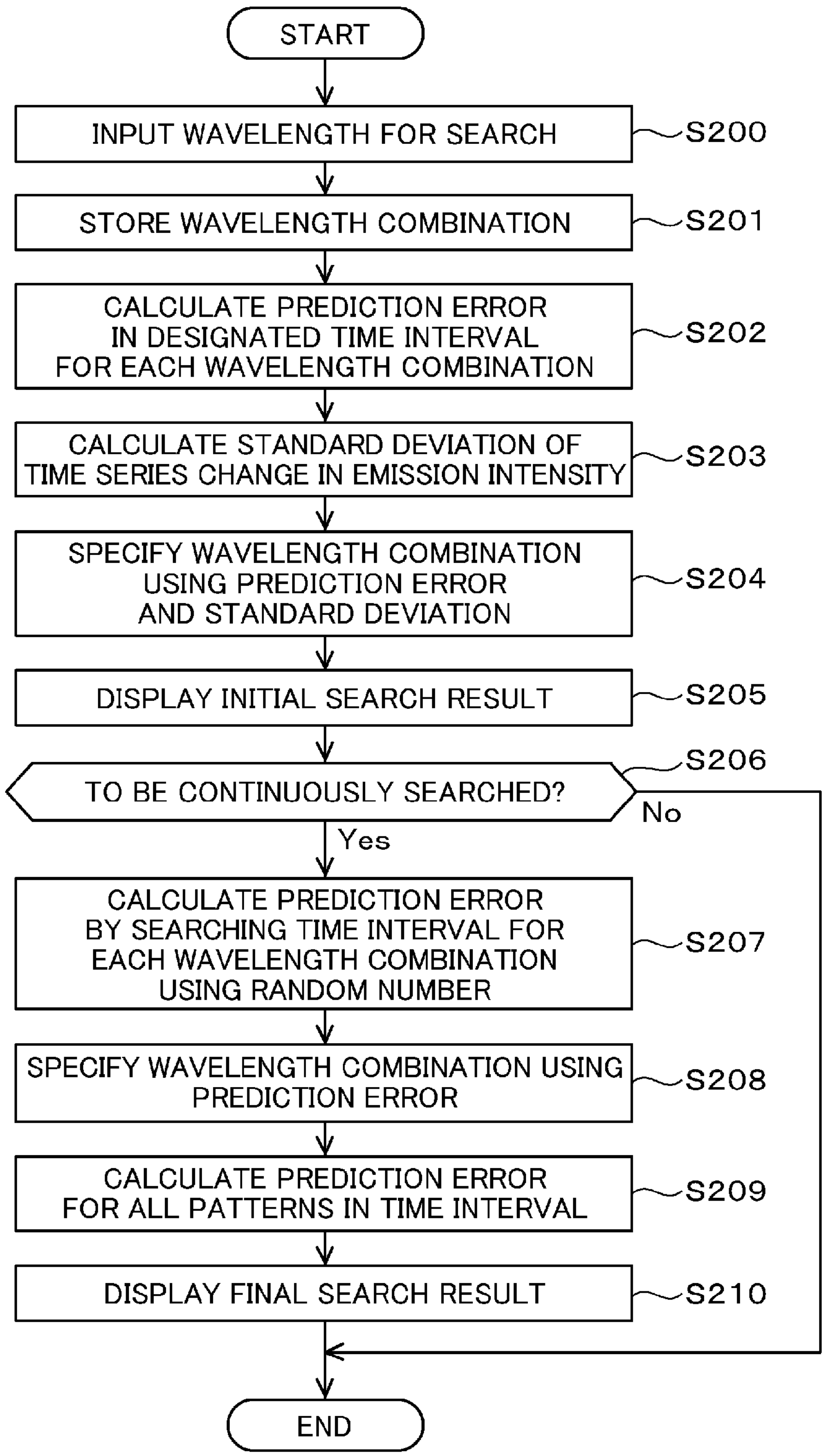
ID (26b)	WAVELENGTH 1 (26c)	WAVELENGTH 2 (26d)	WAVELENGTH 1-TIME INTERVAL (26e)	WAVELENGTH 2-TIME INTERVAL (26f)	PREDICTION ERROR (26g)	PREDICTION ERROR RANK (26h)	CONTINUOUS SEARCH (26i)
1000	251	772	63-87	12-90	0.015	1	○
1200	288	772	72-90	22-89	0.018	4	-
...	...	...	...	...	...	...	...

FIG. 9

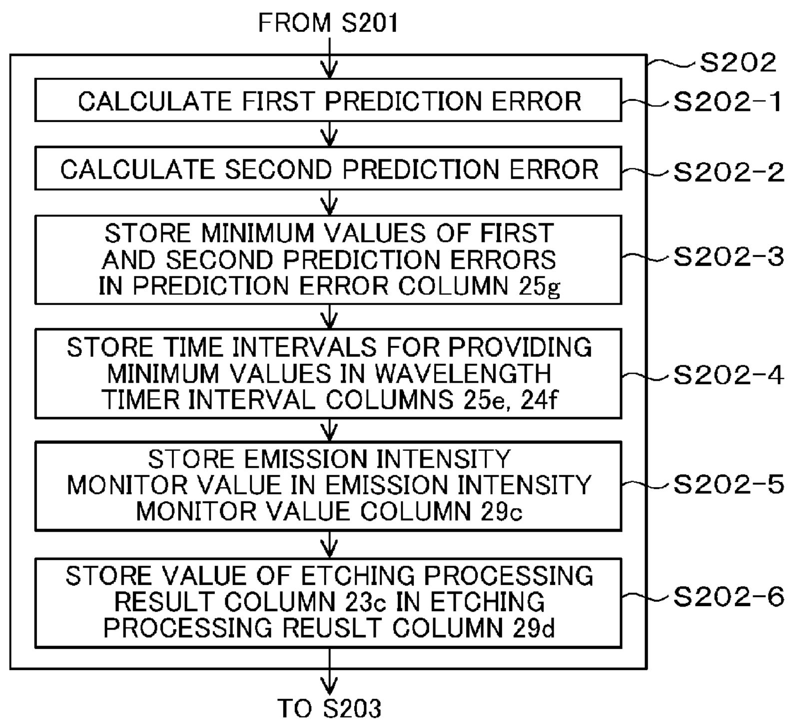
27a

ID (27b)	WAVELENGTH 1 (27c)	WAVELENGTH 2 (27d)	WAVELENGTH 1-TIME INTERVAL (27e)	WAVELENGTH 2-TIME INTERVAL (27f)	PREDICTION ERROR (27g)
1000	251	772	66-87	11-87	0.014

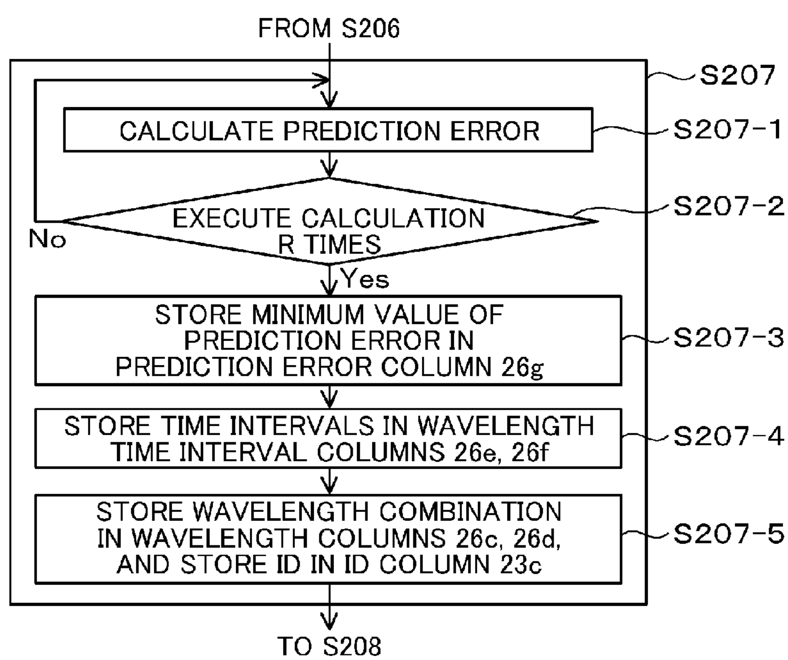
FIG. 10A


START
INPUT WAVELENGTH FOR SEARCH
S200
STORE WAVELENGTH COMBINATION
S201
CALCULATE PREDICTION ERROR IN DESIGNATED TIME INTERVAL FOR EACH WAVELENGTH COMBINATION
S202
CALCULATE STANDARD DEVIATION OF TIME SERIES CHANGE IN EMISSION INTENSITY
S203
SPECIFY WAVELENGTH COMBINATION USING PREDICTION ERROR AND STANDARD DEVIATION
S204
DISPLAY INITIAL SEARCH RESULT
S205
TO BE CONTINUOUSLY SEARCHED?
S206
No
Yes
CALCULATE PREDICTION ERROR BY SEARCHING TIME INTERVAL FOR EACH WAVELENGTH COMBINATION USING RANDOM NUMBER
S207
SPECIFY WAVELENGTH COMBINATION USING PREDICTION ERROR
S208
CALCULATE PREDICTION ERROR FOR ALL PATTERNS IN TIME INTERVAL
S209
DISPLAY FINAL SEARCH RESULT
S210
END

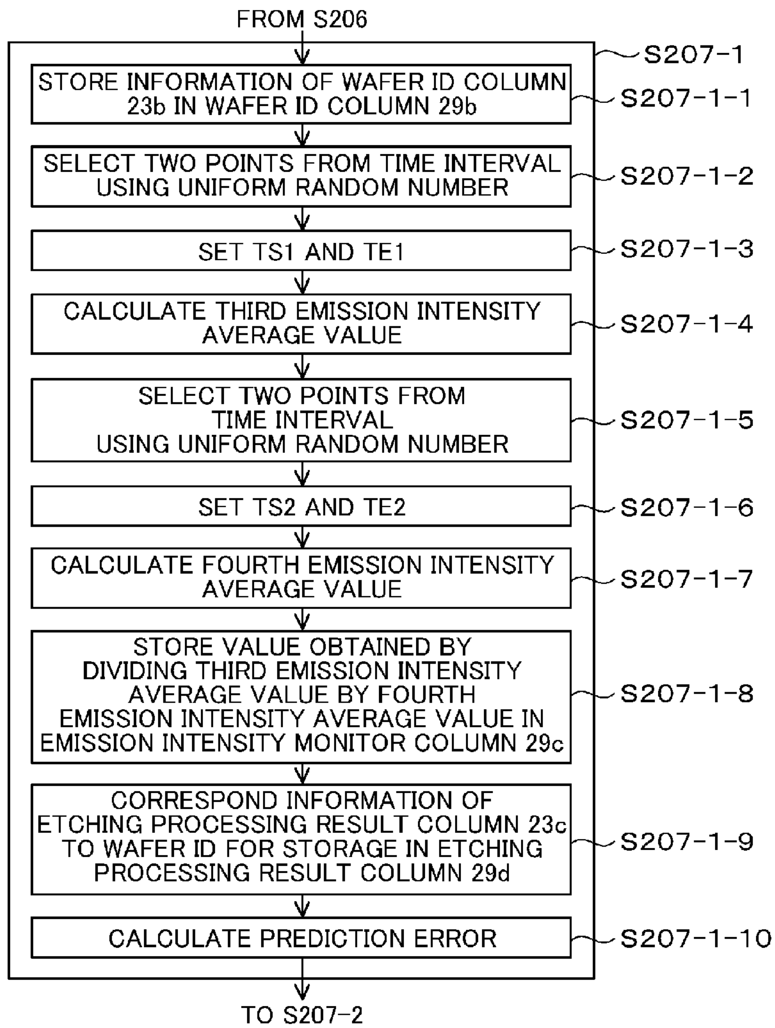
F I G. 1 0 B



F I G. 1 0 C



F I G. 1 0 D



F I G. 1 1

29a

29b	WAVER ID	p1	p2	···	p100
29c	EMISSION INTENSITY MONITOR VALUE	1.06	1.21	···	0.93
29d	ETCHING PROCESSING RESULT	0.75	0.80	···	0.71

FIG. 12

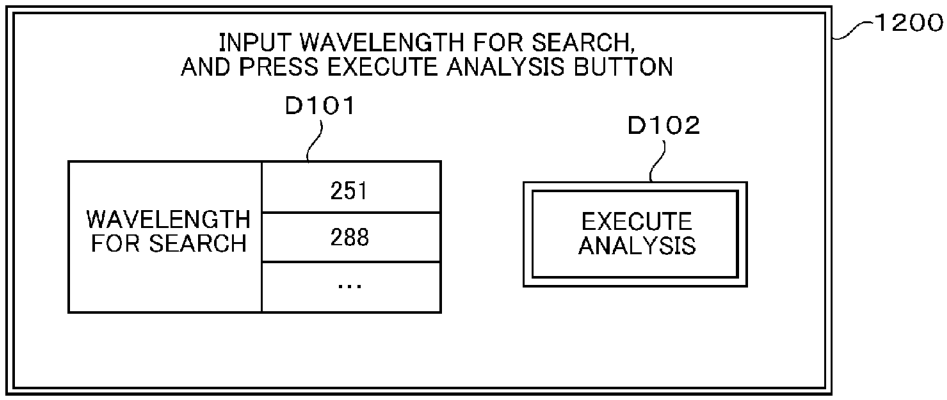


FIG. 13A

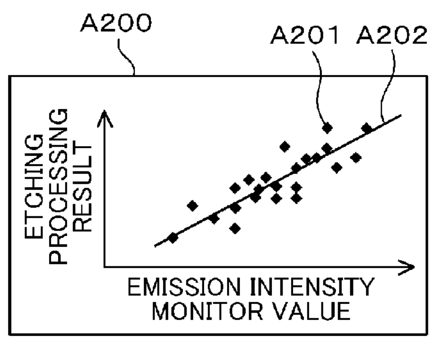
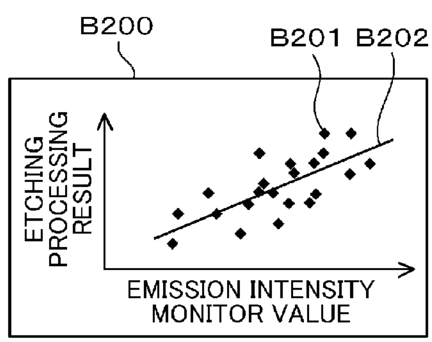
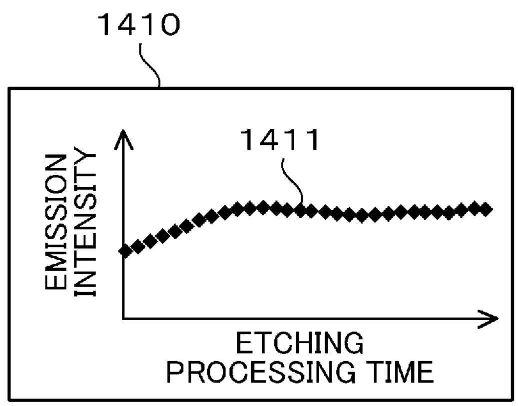


FIG. 13B



F I G. 1 4 A



F I G. 1 4 B

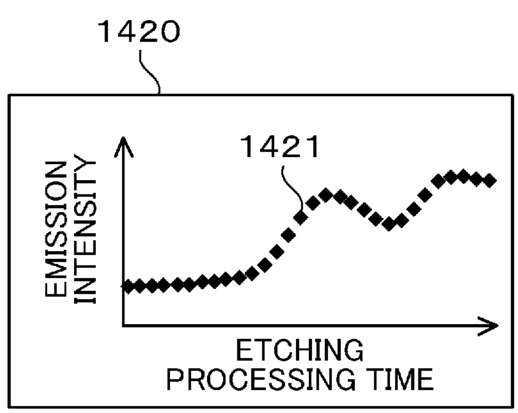


FIG. 15

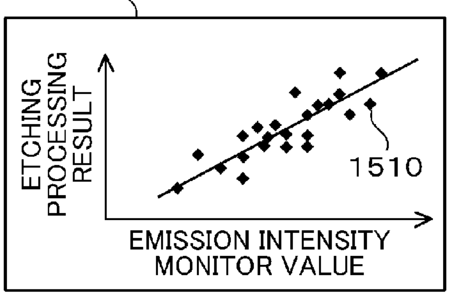
1500

COMBINATIONS OF WAVELENGTH AND TIME INTERVAL BELOW ARE SEARCHED D200

D201 PREDICTION ERROR RANK	D202 WAVELENGTH 1	D203 WAVELENGTH 2	D204 WAVELENGTH 1-TIME INTERVAL	D205 WAVELENGTH 2-TIME INTERVAL	D206 PREDICTION ERROR
1	288	772	51-100	1-100	0.019
2	251	772	51-100	1-100	0.021
...	...	...	...	...	...

SCATTER CHART OF FIRST-RANKED COMBINATION OF WAVELENGTH AND TIME INTERVAL

D207



D208

IS CONTINUOUS SEARCH REQUIRED?

D209 Yes

D210 No

FIG. 16

1600

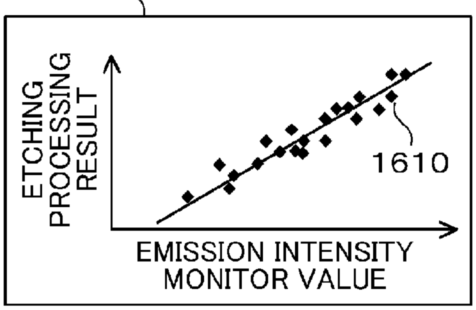
COMBINATIONS OF WAVELENGTH AND TIME INTERVAL BELOW ARE SEARCHED

D300

D301 PREDICTION ERROR RANK	D302 WAVELENGTH 1	D303 WAVELENGTH 2	D304 WAVELENGTH 1-TIME INTERVAL	D305 WAVELENGTH 2-TIME INTERVAL	D306 PREDICTION ERROR
1	251	772	66-87	11-87	0.014

SCATTER CHART OF FIRST-RANKED COMBINATION OF WAVELENGTH AND TIME INTERVAL

D307



DATA ANALYSIS METHOD FOR PLASMA PROCESSING APPARATUS, PLASMA PROCESSING METHOD AND PLASMA PROCESSING APPARATUS

BACKGROUND

The present invention relates to a method of analyzing data of a plasma processing apparatus for processing a semiconductor wafer through plasma, a plasma processing method, and a device used for the plasma processing method.

In order to obtain the micro shape of the semiconductor device to be formed on the wafer, plasma processing such as an etching process is performed for bringing a substance into an ionized state (plasma state) so as to remove the substance on the wafer through its action (reaction on the wafer surface).

The plasma processing apparatus such as the etching apparatus for processing with plasma is equipped with a spectroscope (OES: Optical Emission Spectroscopy) which allows monitoring of the plasma light in order to cope with light emission resulting from ionizing phenomenon caused by the plasma. The data measured by the spectroscope will be referred to as OES data.

In order to stabilize the micro shape of the semiconductor device, the etching apparatus is structured to apply control technology to measure the OES data, predict etching processing results such as dimension of the micro shape, and adjust the etching processing condition.

It is necessary to predict the etching processing results with minimum error by using the OES data for stabilization of the etching processing result.

There is a known method of predicting the etching processing result as disclosed in JP-4547396.

JP-4547396 discloses the method of predicting the etching processing result by selecting monitor data and the corresponding time interval which are used for predicting the etching processing result from monitor data of the apparatus, including the OES data, and predicting the etching processing result using values only of the selected monitor data and the time interval, and the method of adjusting the etching processing condition in accordance with the prediction result.

SUMMARY

JP-4547396 merely discloses the method of specifying the time interval with small prediction error of the etching processing result. The value of the OES data varies depending on the wavelength of emitted light, and changes over time during etching process. The prediction error may become large depending on combination of the selected wavelength and time interval. In order to stabilize the etching processing result, it is necessary to specify the combination of the wavelength and the time interval, which exhibits the small prediction error of the etching processing result. Because of a huge number of combinations of wavelength and time interval, it is further necessary to specify the combination with small prediction error from those combinations within a short period in view of practical application for daily work.

An object of the invention is to provide a data analysis method of an etching apparatus, capable of executing the etching process stabilized at an earlier stage by specifying both wavelength and time interval, which exhibit small prediction error of the etching processing result within a short period, an etching method using the analysis result, and the device used for the method.

The present invention provides a data analyzing method including the steps of generating a combination of wavelength and time interval from wavelength band of plasma emission generated by etching a specimen, calculating a prediction error upon prediction of an etching processing result with respect to the generated combinations of wavelength and time interval, specifying the wavelength combination based on the calculated prediction error to further calculate the prediction error by changing the time interval with respect to the specified wavelength combination, and selecting the wavelength combination, which exhibits a minimum value of the calculated prediction error, as the wavelength and the time interval used for predicting the etching processing result.

The present invention provides the etching method including the steps of etching a specimen inside an exhausted vacuum processing chamber by introducing etching gas into the chamber to generate plasma while monitoring emission of the generated plasma under a predetermined etching processing condition, generating a wavelength combination from wavelength band of plasma emission generated by etching the specimen, calculating a prediction error upon prediction of an etching processing result with respect to the respectively generated wavelength combination, specifying the wavelength combination based on the calculated prediction error, further calculating the prediction error by changing the time interval with respect to the specified wavelength combination, selecting the combination of wavelength and time interval, which exhibits a minimum value of the calculated prediction error, as the wavelength and the time interval used for predicting the etching processing result, and adjusting the etching processing condition using a prediction value of the etching processing result with respect to the selected wavelength and time interval.

The present invention provides an etching apparatus which includes a processing chamber, a plasma generating unit for generating plasma by introducing etching gas into the processing chamber exhausted in vacuum, in which a specimen is disposed, an emission monitor unit for monitoring emission of the plasma generated by the plasma generating unit, an arithmetic unit for generating data concerning a condition of controlling the plasma generating unit, a storage unit for storing the data concerning condition of controlling the plasma generating unit, which has been generated by the arithmetic unit, and a control unit for controlling the plasma generating unit based on a state of the plasma emission monitored by the plasma emission monitor unit and the control data stored in the storage unit. The arithmetic unit generates a wavelength combination from wavelength band of the plasma emission to be generated by etching the specimen as a condition for etching the specimen by the plasma generating unit, calculates a prediction error for prediction of the etching processing result with respect to the combinations of wavelength and time interval, specifies a wavelength combination based on the calculated prediction error, further calculates the prediction error by changing the time interval with respect to the specified wavelength combination, and selects the combination of wavelength and time interval, which exhibits a minimum value of the further calculated prediction error, as the wavelength and the time interval used for prediction of the etching processing result so as to generate the condition for etching the set specimen.

The present invention ensures to specify the combination of wavelength and time interval, which only exhibits small prediction error of the etching processing result from the OES data, and to stabilize the etching processing result.

These features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram schematically representing a structure of an etching apparatus according to an embodiment of the invention;

FIG. **2** is a block diagram schematically representing a structure of an etching section of the etching apparatus according to the present embodiment of the invention;

FIG. **3** is a graph representing an example of the OES data;

FIG. **4** shows a flowchart explaining an example of the control for adjusting the etching processing condition and a scatter chart representing a relationship between the emission intensity monitor values and the etching processing result;

FIG. **5** is a table representing an example of etching processing result data according to an embodiment of the invention;

FIG. **6** is a table representing an example of OES data according to an embodiment of the invention;

FIG. **7** is a table representing an example of initial search result data according to an embodiment of the invention;

FIG. **8** is a table representing an example of random number search result data according to an embodiment of the invention;

FIG. **9** is a table representing an example of final search result data according to an embodiment of the invention;

FIG. **10**A is a flowchart representing an analyzing process flow performed by an arithmetic unit according to an embodiment of the invention;

FIG. **10**B is a flowchart representing the analyzing process flow performed by the arithmetic unit according to the present embodiment of the invention, and specifically, details of step S**202** of the flow shown in FIG. **10**A;

FIG. **10**C is a flowchart representing the analyzing process flow performed by the arithmetic unit according to the present embodiment of the invention, and specifically, details of step S**207** of the flow shown in FIG. **10**B;

FIG. **10**D is a flowchart representing the analyzing process flow executed by the arithmetic unit according to the present embodiment of the invention, and specifically, details of step S**207-1** of the flow shown in FIG. **10**C;

FIG. **11** is a table of data representing emission intensity monitor values used for calculating a prediction error according to an embodiment of the invention;

FIG. **12** is a front view of a screen displaying a section for input of wavelength for search and an analysis execution button according to an embodiment of the invention;

FIG. **13**A is a scatter chart representing a relationship between the emission intensity monitor values and the etching processing results for explaining the process of calculating the prediction error according to an embodiment of the invention;

FIG. **13**B is a scatter chart representing a relationship between the emission intensity monitor values and the etching processing results for explaining the process of calculating the prediction error according to an embodiment of the invention;

FIG. **14**A is a scatter chart representing a relationship between the etching processing time and the emission intensity, indicating a time series change in the emission intensity according to an embodiment of the invention;

FIG. **14**B is a scatter chart representing a relationship between the etching processing time and the emission intensity, indicating a time series change in the emission intensity according to an embodiment of the invention;

FIG. **15** is a front view of the screen displaying the initial search result according to an embodiment of the invention; and

FIG. **16** is a front view of the screen displaying the final search result according to an embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The method of analyzing data of the etching apparatus according to the invention allows acquisition of plasma emission data indicating the emission intensity with respect to a plurality of values of wavelength and time, which are obtained upon the etching process and the etching processing result, and evaluation of a prediction error of the etching processing result based on the average value of the emission intensity with respect to different combinations of wavelength and the time interval of the plasma emission data. This enables to specify the combination of wavelength and time interval of the plasma emission data used for prediction of the etching processing result based on the prediction error. This process is applied to the etching method and the etching apparatus. An embodiment of the invention will be described referring to the drawings. For all the drawings referred to explain the present embodiment, the same elements are designated with the same codes, and repetitive explanations thereof, thus, will be omitted.

Etching Apparatus

As the structure of an etching apparatus according to the invention of FIG. **1** indicates, an etching apparatus **1** includes an etching section **10**, an analyzing section **20**, an input section **30**, an output section **31**, and a communication interface section (communication IF section) **32**, which are mutually connected with one another via a bus **33**.

The etching section **10** includes a plasma processing unit **11**, a spectroscope (OES) **12**, a control unit **13**, and an interface unit (IF unit) **14**. The plasma processing unit **11** generates plasma to process the wafer. The spectroscope (OES) **12** acquires the OES data as the plasma emission data during the etching process. The OES data are stored in a storage unit **22** of the analyzing section **20** via the IF unit **14**. The control unit **13** controls processing performed by the plasma processing unit **11**. The etching section **10** will be described later in detail referring to FIG. **2**.

The analyzing section **20** executes the process of specifying the combination of wavelength and time interval, which is used for prediction of the etching processing result. The analyzing section **20** includes an arithmetic unit **21** for data analysis, the storage unit **22**, and an interface unit (IF unit) **210**.

The storage unit **22** includes an etching processing result data storage region **23** for storing the etching processing result for each wafer, an OES data storage region **24** for storing measurement values of the spectroscope (OES) which are acquired during the etching process, an initial search result data storage region **25** for storing initial search result data of the search process performed by the arithmetic unit **21**, a random number search result data storage region **26** for storing data of a random search result performed by the arithmetic unit **21**, a final search result data storage region **27** for storing final search result data, and a control condition data storage region **28** for storing conditions to be controlled by the plasma processing unit **11** for etching process of the wafer.

The arithmetic unit **21** sequentially evaluates the prediction error for prediction of the etching result in accordance with the emission intensity for each combination of wavelength and time interval in the etching processing result data storage region **23** of the storage unit **22**, and the OES data stored in the OES data storage region **24**. Then the arithmetic unit further specifies the combination of wavelength and time interval, which is used for prediction of the etching processing result. The analyzing process performed by the arithmetic unit **21** will be described later in detail.

The input section **30** is formed as a mouse, a keyboard and the like for receiving information input through operation of the user. The output section **31** is formed as a display, a printer and the like for outputting the information to the user. The communication IF section **32** is formed as an interface connected to another device (connectable to the inspection device for measuring etching processing results) and the system (connectable to the existing production management system) via the bus **33**, an external network and the like for receiving and transmitting the information. The bus **33** serves to link the respective sections (**10**, **20**, **30**, **31**, **32**). Each of the IF units (**14**, **210**) in the respective sections is the interface for receiving and transmitting the information via the bus **33**. The analyzing section **20** may be formed as an independent analyzing device which is connected to the etching apparatus including the etching section **10** via the IF unit **210**.

Etching Section

The etching section **10** includes the plasma processing unit **11**, the spectroscope (OES) **12**, the control unit **13**, and the IF unit **14**. The plasma processing unit **11** includes a chamber **111** that is vacuumed by a not-shown vacuum exhaust unit, a pair of electrodes **112***a*, **112***b* which generate plasma inside the vacuum exhausted chamber **111** in response to application of radio frequency power from a not-shown power source, a window **115** which allows observation of the inside of the chamber **111** from outside, and a gas supplier **117** in the vacuum exhausted chamber **111** for supplying etching gas so as to subject the wafer **114** to the etching process.

In the aforementioned structure, the plasma processing unit **11**, according to an instruction from the control unit **13**, generates plasma from the etching gas supplied from the gas supplier **117** through the not-shown power source between the electrodes **112***a* and **112***b* to which the radio frequency power is applied in the state where the chamber **111** that stores the wafer **114** is vacuum exhausted by the not-shown exhaust unit. The plasma gas **113** is impinged on the wafer **114** so as to be processed.

The thus generated plasma gas **113** includes an element contained in the etching gas supplied by the gas supplier **117** and an element generated from the wafer **114** in processing, and emits a light ray **116** with wavelength in accordance with the element contained in the plasma gas **113**. The emitted light **116** is measured by the spectroscope (OES) **12** through the window **115**, and stored in the OES data storage region **24** of the storage unit **22** in the analyzing section **20** via the IF unit **14**.

The control unit **13** serves to adjust an etching processing condition by inputting the OES data measured by the spectroscope (OES) **12** as the process of adjusting the etching processing condition to be described later in addition to an instruction given to the plasma processing unit **11**.

At the end of the etching process, the processed wafer **114** is taken from the chamber **111**, and carried to another device (measurement device, for example) so that another new wafer **114** is stored in the etching section **10** for the etching process. The processed wafer **114** is subjected to measurement of a dimension of the pattern shape obtained as a result of the etching process performed by another device (measurement device). The dimension of the shape may be stored in the etching processing result data storage region **23** of the storage unit **22** as the etching processing result data.

OES Data

FIG. **3** shows a waveform signal **301** as an example of the OES data of plasma emission measured by the spectroscope (OES) **12**. The wavelength band and intensity of the plasma emission will vary as passage of time during the etching process. The waveform signal **301** of the OES data includes two dimensional elements of wavelength and time, indicating the value of the emission intensity measured with respect to each waveform and each time. The value of the emission intensity measured for each waveform and each time will be stored in the OES data storage region **24** to be described later together with the wafer ID having the OES data measured.

Etching Processing Condition Adjustment Process

FIG. **4** shows an example of the etching processing condition adjustment process performed by the control unit **13**. The control unit **13** calls control data stored in the control condition data storage region **28** of the storage unit **22** in response to an instruction of an operator to adjust the etching processing condition (**S101**). The etching processing condition adjustment process is sequentially performed for a plurality of wafers using the control data stored in the control condition data storage region **28**. The first wafer is processed under the preliminarily set condition.

The average value of the emission intensity of a predetermined combination of wavelength and time interval is calculated, or the average value of emission intensity of a predetermined combination of wavelength and time interval is divided by the average value of emission intensity of another predetermined combination of wavelength and time interval (**S102**). The value derived from dividing the average value of the emission intensity of the predetermined combination of wavelength and time interval by the average value of emission intensity of another predetermined combination of wavelength and time interval will be hereinafter referred to as an emission intensity monitor value. The average value of emission intensity of the predetermined combination of wavelength and time interval may be set to the emission intensity monitor value.

The control unit **13** predicts the etching processing result upon input of the aforementioned emission intensity monitor value (**S103**). A graph **A101** shows an example of the process of predicting the etching processing result executed in **S103**. A y-axis and an x-axis of the graph **A101** represent the etching processing result and the emission intensity monitor value, respectively. Each point **A102** on the graph represents each sheet of the wafer. The graph shows the correlation between the emission intensity monitor value and the etching processing result. A straight line **A103** is a regression line indicating the relationship between the emission intensity monitor value derived from a plurality of points **A102** and the etching processing result. The straight line **A103** is drawn so that the sum of squares of the distance from each point of a plurality of points **A102** is minimized. In **S103**, the regression line **A103** is used to calculate a prediction value (pv) of the etching processing result from the emission intensity (ei) as a dotted line shown in the drawing.

The control unit **13** calculates the difference between a target value and a prediction value (pv) of the etching processing result (S**104**). Based on the difference, the control unit calculates an adjustment value of the etching processing condition, for example, the flow rate of the etching gas (gas flow rate) supplied from the gas supplier **117**, and time taken for executing the etching process (S**105**).

The control unit **13** executes the etching process under the adjusted etching processing condition after completion of the process of adjusting etching processing condition.

Analyzing Section

The information that specifies ID of the wafer subjected to the etching process, and the information that specifies the etching processing result will be stored in the etching processing result data storage region **23** of the storage unit **22** shown in FIG. **1**.

FIG. **5** shows an etching processing result data table **23***a* as an example of the etching processing result data storage region **23**. This table includes fields of columns **23***b* for wafer ID and **23***c* for etching processing result.

The information that specifies the wafer **114** is stored in the column **23***b* for wafer ID. The value to be stored in the column **23***b* for wafer ID is corresponded to the value stored in a column **25***b* for wafer ID of an OES data table **25***a* which will be described later so that the OES data derived from etching the respective wafers are corresponded to the etching processing results.

The information that specifies the etching processing result is stored in the column **23***c* for etching processing result. For example, the measurement result of the surface shape of the wafer **114** specified in the column **23***b* for wafer ID (for example, dimension of the pattern formed on the wafer **114** measured with a length measuring SEM, and dimension between patterns) which is measured after the etching process by using the measurement device which is connected to the etching apparatus **1**. The dimension information of the surface shape for each wafer is stored in the etching processing result data storage region **23** via the communication IF section **32**.

FIG. **6** shows an OES data table **24***a* as an example of the OES data storage region **24**. This table includes fields of columns **24***b* for wafer ID, **24***c* for wavelength, **24***d* for time, and **24***e* for emission intensity. The number of the tables corresponds to the number of wafers subjected to the OES data measurement.

The column **24***b* for wafer ID stores the information that specifies the wafer **114**. The value stored in the column **24***b* for wafer ID corresponds to the value to be stored in the column **23***b* for wafer ID of the etching processing result data table **23***a* as described above.

The column **24***e* for emission intensity stores the value of emission intensity measured for each wavelength in the column **24***c* for wavelength, and each time in the column **24***d* for time, respectively.

FIG. **7** shows an initial search result data table **25***a* as an example of the initial search result data storage region **25**. This table includes various fields of columns **25***b* for ID, **25***c* for wavelength **1**, **25***d* for wavelength **2**, **25***e* for wavelength **1**-time interval, **25***f* for wavelength **2**-time interval, **25***g* for prediction error, **25***h* for prediction error rank, **25***i* for continuous search, **25***j* for standard deviation of emission intensity, **25***k* for prediction error rank **1**, and **251** for prediction error rank **2**.

Each field stores the information obtained through the analyzing process to be described later.

The column **25***b* for ID stores the information that specifies the wavelength combination. The column **25***c* for wavelength **1** stores the information that specifies a candidate of the wavelength used for prediction of the etching processing result. The value stored in a line i of the column **25***c* for wavelength **1** will be referred to as WL**1** for explanation to be described later.

The column **25***d* for wavelength **2** stores the information that specifies a candidate of the wavelength used for prediction of the etching processing result. The value stored in a line i of the column **25***d* for wavelength **2** will be referred to as WL**2** for explanation to be described later.

The column **25***e* for wavelength **1**-time interval stores the information that specifies a candidate of the time interval used for prediction of the etching processing result. The value stored in a line i of the column **25***e* for wavelength **1**-time interval will be referred to as WLT**1** for explanation to be described later.

The column **25***f* for wavelength **2**-time interval stores the information that specifies a candidate of the time interval to be used for prediction of the etching processing result. The value stored in a line i of the column **25***f* for wavelength **2**-time interval will be referred to as WLT**2** for explanation to be described later.

Values stored in the columns **25***c* for wavelength **1**, **25***d* for wavelength **2**, **25***e* for wavelength **1**-time interval, and **25***f* for wavelength **2**-time interval are used to predict the etching processing result in accordance with the emission intensity monitor value derived from dividing the average value of the emission intensity in the time interval WLT**1** stored in the column **24***d* for time with respect to the wavelength WL**1** stored in the column **24***c* for wavelength of the OES data table **24***a* in the OES data storage region **24** as shown in FIG. **6** by the average value of the emission intensity in the time interval WLT**2** stored in the column **24***d* for time with respect to the wavelength WL**2** stored in the column **24***c* for wavelength.

The column **25***g* for prediction error stores the information that specifies the prediction error for predicting the etching processing result using the calculated emission intensity monitor value in accordance with values stored in the columns **25***c* for wavelength **1**, **25***d* for wavelength **2**, **25***e* for wavelength **1**-time interval, and **25***f* for wavelength **2**-time interval.

The column **25***h* for prediction error rank stores the value that indicates the rank among information data stored in the respective lines of the column **25***g* for prediction error. The column **25***i* for continuous search stores the information that specifies the wavelength combination for continuous search in the time interval. The column **25***j* for standard deviation of emission intensity stores the information that specifies the standard deviation of the time series change in the emission intensity.

The column **25***k* for prediction error rank **1** stores the value indicating the rank of information data stored in the respective lines of the column **25***g* for prediction error. Such value is calculated with respect to the group (group of small standard deviation value) in the line, having the value stored in the column **25***j* for standard deviation of emission intensity smaller than a predetermined threshold value.

The column **25***l* for prediction error rank **2** stores the value indicating the rank of information data stored in the respective lines of the column **25***g* for prediction error. Such value is calculated with respect to the group (group of large standard deviation value) in the line, having the value stored in the column **25***j* for standard deviation of emission intensity equal to or larger than the predetermined threshold value.

FIG. **8** shows a random number search result data table **26***a* as an example of the random number search result data storage region **26**. This table includes fields of columns **26***b* for ID, **26***c* for wavelength **1**, **26***d* for wavelength **2**, **26***e* for wavelength **1**-time interval, **26***f* for wavelength **2**-time interval, **26***g* for prediction error, **26***h* for prediction error rank, and **26***i* for continuous search.

Each field stores the information obtained through the analyzing process to be described later.

The column **26***b* for ID stores the information that specifies the wavelength combination common with the one stored in the column **25***b* for ID of the initial search result data table **25***a* shown in FIG. **7**. The column **26***c* for wavelength **1** stores the information that specifies a candidate of the wavelength used for prediction of the etching processing result. The column **26***d* for wavelength **2** stores the information that specifies a candidate of the wavelength used for prediction of the etching processing result.

The column **26***e* for wavelength **1**-time interval stores the information that specifies a candidate of the time interval used for prediction of the etching processing result.

The column **26***f* for wavelength **2**-time interval stores the information that specifies a candidate of the time interval used for prediction of the etching processing result.

Like the initial search result data storage region **25** as described above, values stored in the columns **26***c* for wavelength **1**, **26***d* for wavelength **2**, **26***e* for wavelength **1**-time interval, and **26***f* for wavelength **2**-time interval represent each wavelength of emission and time interval for predicting the etching processing result.

The column **26***g* for prediction error stores the information that specifies the prediction error for predicting the etching processing result using the emission intensity monitor value calculated with values stored in the columns **26***c* for wavelength **1**, **26***d* for wavelength **2**, **26***e* for wavelength **1**-time interval, and **26***f* for wavelength **2**-time interval.

The column **26***h* for prediction error rank stores the value representing the rank of information data stored in the respective lines of the column **26***g* for prediction error.

The column **26***i* for continuous search stores the information that specifies the wavelength combination for continuous search in the time interval.

FIG. **9** shows a final search result data table **27***a* as an example of the final search result data storage region **27**. This table includes fields of columns **27***b* for ID, **27***c* for wavelength **1**, **27***d* for wavelength **2**, **27***e* for wavelength **1**-time interval, **27***f* for wavelength **2**-time interval, and **27***g* for prediction error.

Each field stores the information obtained through the analyzing process to be described later.

The column **27***b* for ID stores the information that specifies the wavelength combination common with the one stored in the column **25***b* for ID of the initial search result data table **25***a* shown in FIG. **7**. The column **27***c* for wavelength **1** stores the information that specifies a candidate of the wavelength used for prediction of the etching processing result. The column **27***d* for wavelength **2** stores the information that specifies a candidate of the wavelength used for prediction of the etching processing result.

The column **27***e* for wavelength **1**-time interval stores the information that specifies a candidate of the time interval used for prediction of the etching processing result.

The column **27***f* for wavelength **2**-time interval stores the information that specifies a candidate of the time interval used for prediction of the etching processing result.

Like the explanation with respect to the initial search result data storage region **25**, values stored in the columns **27***c* for wavelength **1**, **27***d* for wavelength **2**, **27***e* for wavelength **1**-time interval, and **27***f* for wavelength **2**-time interval represent the wavelength of emission and time interval of emission for predicting the etching processing result.

The column **27***g* for prediction error stores the information that specifies the prediction error for predicting the etching processing result using the emission intensity monitor value calculated with values stored in the columns **27***c* for wavelength **1**, **27***d* for wavelength **2**, **27***e* for wavelength **1**-time interval, and **27***f* for wavelength **2**-time interval.

Analyzing Process in Analyzing Section **20**

The analyzing process according to the present embodiment is the method of specifying the wavelength of plasma emission data and time which are used for prediction of the etching processing result in the semiconductor etching process which etches the semiconductor wafer with plasma.

The method of analyzing process according to the present embodiment includes six steps. In the first step, calculating a prediction error upon prediction of the etching processing result using the emission intensity average value in a first half of the time interval in the etching process as well as a prediction error used for the prediction of the etching processing result using the emission intensity average value in a second half of the time interval in the etching process for each candidate of the wavelength used for prediction. In the second step, specifying a plurality of wavelength values each with small calculated prediction error. In the third step, calculating the prediction error in predicting an etching result by using an emission intensity average value in the respectively set time intervals which are set by using the random number for each of the specified plurality of wavelength values and. In the fourth step, specifying the wavelength value with small prediction error calculated in the second evaluation step. In the fifth step, calculating the prediction error in predicting an etching processing result by using emission intensity average values for each of all possible time intervals with respect to the specified wavelength. And in the sixth step, specifying a combination of wavelength and time interval, which is used for prediction of the etching processing result, by specifying the time interval with the minimum prediction error from all possible time intervals with respect to the specified wavelength.

The specific method of analyzing process according to the present embodiment will be described.

In a stage before sequentially etching a plurality of wafers using the etching apparatus **1** in the production process, an operator or a manager of the etching apparatus **1** executes the analyzing process through the analyzing section **20** for determining the combination of wavelength and time interval for prediction of the etching processing result.

Since the combination of wavelength and time interval suitable for prediction of the etching processing result varies depending on the film structure on the surface of the semiconductor wafer to be subjected by the etching process, it is necessary to execute the analyzing process as needed upon start of the etching process. Using the etching processing condition determined by the aforementioned analyzing process, a plurality of wafer are sequentially subjected to the etching process through the etching apparatus **1** in the production process (mass-production process).

In execution of the analyzing process through the analyzing section **20**, the condition for executing the analyzing process is input on a display screen **1200** as shown in FIG. **12**. The operator inputs the wavelength for search in the column D**101** for input of wavelength for search on the display screen **1200**, and clicks an analyzing execute button D**102** to instruct execution of analysis. The analyzing section **20** then performs the analyzing process to output the combination of wavelength and time interval, which is suitable for prediction of the etching processing result.

The column D**101** for input of the wavelength for search on the display screen **1200** stores the information that specifies the wavelength for evaluating the prediction error. The predetermined wavelength (wavelength determined at an equal interval, for example, **201**, **211**) may be automatically input in the column D**101** for input of the wavelength for search. The wavelength indicating emission of an element contained in the plasma gas **113** may also be automatically input. The wavelength having the emission intensity higher than that of the peripheral wavelength, that is, the wavelength indicating the plasma emission peak may also be input in the column. The analyzing process flow performed by the analyzing section **20** will be described referring to FIGS. **10**A to **10**D.

The wavelength for search is input in the column D**101** for input of wavelength for search on the display screen **1200** shown in FIG. **12** (S**200**). Then the combination of wavelength for search which has been input in S**200** is generated, and stored in the initial search result data table **25***a* shown in FIG. **7** (S**201**). The prediction error in the designated time interval with respect to the combination of wavelength for search generated in S**201** is calculated (S**202**). The standard deviation of time series change in the plasma emission intensity is calculated (S**203**). The wavelength combination is specified using the prediction error calculated in S**202** and the standard deviation calculated in S**203** (S**204**). The initial search result is displayed on the screen (S**205**).

It is determined whether or not the search is to be continued (S**206**). If the search is not continued (No in S**206**), the process ends. Meanwhile, if the search is continued (Yes in S**206**), the time interval is searched for each wavelength combination using the random number to calculate the prediction error (S**207**). The wavelength combination is specified using the thus calculated prediction error (S**208**). The prediction error for all the patterns in the time interval is calculated with respect to the specified wavelength combination (S**209**). The final search result is displayed (S**210**), and the process ends.

The respective process steps will be described in detail.

In S**201**, the arithmetic unit **21** generates a plurality of combinations of two wavelengths using a plurality of wavelengths for search which have been input in the column D**101** for input of wavelength for search on the display screen **1200** in S**200** as shown in FIG. **12** so that each wavelength of the combinations is stored in the columns **25***c* for wavelength **1** and **25***d* for wavelength **2** of the initial search result data table **25***a*, respectively as shown in FIG. **7**. The combination to be stored may be those of all the wavelengths input in the column D**101** for input of wavelength as shown in FIG. **12**. The arithmetic unit **21** sequentially performs numbering from the first line sequentially in the column **25***b* for ID as shown in FIG. **7**.

In S**202**, the arithmetic unit **21** outputs the prediction error of the etching processing result derived from calculating the emission intensity monitor value in the designated time interval with respect to the wavelength combinations stored in the respective lines of the initial search result data table **25***a* shown in FIG. **7**. The arithmetic unit **21** sequentially executes the process of the information from the upper line of the initial search result data table **25***a*.

In this step specifically shown in FIG. **10**B, the arithmetic unit **21** performs the process of calculating the first prediction error using the emission intensity in the first half of the time interval in the etching process (S**202-1**), and the process of calculating the second prediction error using the emission intensity in the second half of the time interval in the etching process (S**202-2**). The minimum value of the first and the second prediction error is stored in the corresponding line of the column **25***g* for prediction error (S**202-3**). Then the time interval that provides the minimum value is stored in the columns **25***e* for wavelength **1**-time interval and **25***f* for wavelength **2**-time interval (S**202-4**).

The process of calculating the first prediction error in S**202-1** generates an emission intensity monitor value data table **29***a* shown in FIG. **11** using the emission intensity value in the first half of the time interval in the etching process.

The column **29***b* for wafer ID of the emission intensity monitor value data table **29***a* stores the information that indicates the wafer with acquired data, for example, the information stored in the column **23***b* for wafer ID of the etching processing result table **23***a* shown in FIG. **5**.

The column **29***c* for emission intensity monitor value stores the emission intensity monitor value obtained by dividing the first emission intensity average value by the second emission intensity average value (S**202-5**) as shown below.

The first emission intensity average value is derived from values stored in the column **24***e* for emission intensity of the OES data table **24***a* shown in FIG. **6** at the row specified by the wavelength stored in the corresponding line of the column **25***c* for wavelength **1** of the initial search result data table **25***a* shown in FIG. **7** in the time lines from start to the intermediate stage of the etching process. The time lines from start to the intermediate stage of the etching process correspond to those from 1 to 50 as shown in FIG. **6**, for example.

The second emission intensity average value is derived from values stored in the column **24***e* for emission intensity of the OES data table **24***a* shown in FIG. **6** at the row specified by the wavelength stored in the corresponding line of the column **25***d* for wavelength **2** of the initial search result data table **25***a* shown in FIG. **7** in the time lines from start to the end of the etching process. The time lines from start to the end of the etching process correspond to those from 1 to 100 as shown in FIG. **6**, for example.

The column **29***d* for etching processing result of the emission intensity monitor value data table **29***a* shown in FIG. **11** stores the value stored in the column **23***c* for etching process result of the etching processing result data table **23***a* shown in FIG. **5** so as to be corresponded to the wafer ID (S**202-6**).

In the aforementioned step S**202-1**, the arithmetic unit **21** calculates the prediction error (e) upon prediction of the etching processing result with the emission intensity monitor value through the following formulae (1) to (5). The obtained prediction error (e) becomes the first prediction error.

[Formula 1]

$$X_{11} = \sum x_i^2 - \frac{\left(\sum x_i\right)^2}{n}$$

$$X_{12} = \sum y_i^2 - \frac{\left(\sum y_i\right)^2}{n} \quad \text{[Formula 2]}$$

$$X_{13} = \sum x_i y_i - \frac{\left(\sum x_i\right)\left(\sum y_i\right)}{n} \quad \text{[Formula 3]}$$

$$a = \frac{X_{13}}{X_{11}} \quad \text{[Formula 4]}$$

$$e = \frac{(X_{12} - a\ X_{13})}{n} \quad \text{[Formula 5]}$$

In the above formulae, the code x_i denotes the value stored at the ith row of the column **29***c* for emission intensity monitor value of the emission intensity monitor value data table **29***a* shown in FIG. **11**, and the code y_i denotes the value stored at the ith row of the column **29***d* for etching processing result. The code n denotes the number of rows of the emission intensity monitor value data table **29***a*, and the code E denotes the sum of all the rows of the emission intensity monitor value data table **29***a*.

The calculated value will be described referring to FIGS. **13**A and **13**B. A graph A**200** shown in FIG. **13**A and a graph B**200** shown in FIG. **13**B are scatter charts showing values stored in the column **29***c* for emission intensity monitor value and the column **29***d* for etching processing result.

The points, for example, a point A**201** of the graph A**200** shown in FIG. **13**A, and a point B**201** of the graph B**200** shown in FIG. **13**B, represent values stored in the respective rows of the column **29***c* for emission intensity monitor value of the emission intensity monitor value data table **29***a* shown in FIG. **11**. They are derived from plotting by taking the value stored in the column **29***c* for emission intensity monitor as the horizontal axis, and taking the value stored in the column **29***d* for etching processing result as the vertical axis.

A straight line A**202** of the graph A**200** shown in FIG. **13**A and a straight line B**202** of the graph B**200** shown in FIG. **13**B represent straight lines (recession lines) which minimize the average value of sum of squares of the distance from each point. The first prediction error (e) calculated through the formula 5 represents a square root of sum of squares of the distance between each point and the straight line.

FIGS. **13**A and **13**B are scatter charts for taking the emission intensity monitor values with respect to combinations of different values of wavelength and time interval. Accordingly, values of the etching processing results at the respective points are the same, but those of the emission intensity monitor are different.

Comparing the calculated prediction errors (e) between those shown in the graph A**200** of FIG. **13**A and the graph B**200** of FIG. **13**B, the prediction error (e) of the graph A**200** of FIG. **13**A becomes smaller. Referring to the graph A**200** of FIG. **13**A, the points distribute closer to the recession line comparing to the graph B**200** of FIG. **13**B, and it clearly shows that the emission intensity monitor values of FIG. **13**A are more suitable for prediction of the etching processing result in the aforementioned step of calculating the etching processing result prediction value (S**103**). By selecting the wavelength and the time interval having smaller prediction error (e), it makes possible to set the wavelength and the time interval which are suitable for the process of calculating prediction values of the etching processing result.

The calculated prediction error (e) is stored in the corresponding line of the column **25***g* for prediction error of the initial search result data table **25***a* shown in FIG. **7** as the information for evaluating adequacy of the combination of wavelength and time interval in the subject line.

Any value other than the prediction error calculated herein may be used so long as such value represents dispersion of the prediction result upon prediction of the etching processing result using the emission intensity monitor value. For example, it is possible to use the correlation coefficient or square of correlation coefficient between the emission intensity monitor value and the etching processing result.

In the process step S**202-2** of calculating the second prediction error, like the process step of calculating the first prediction error, the emission intensity value in the second half of time interval in the etching process is used to generate the emission intensity monitor value data table **29***a* shown in FIG. **11**, and to calculate the prediction error (e) upon prediction of the etching processing result using the emission intensity monitor value **29***c* through the formulae 1 to 5. The resultant prediction error (e) becomes the second prediction error.

In calculation of the second prediction error, the column **29***c* for emission intensity monitor value stores the emission intensity monitor value obtained by dividing the first emission intensity average value by the second emission intensity average value as described below.

The first emission intensity average value is derived from values stored at the row specified by the wavelength stored in the corresponding line of the column **25***c* for wavelength **1** of the initial search result data table **25***a* shown in FIG. **7** in the time line from the intermediate stage to the end of the etching process in the column **24***e* for emission intensity of the OES data table **24***a* of FIG. **6**. For example, the time line from the intermediate stage to the end of the etching process represents those from 51 to 100 in the column **24***d* for time shown in FIG. **6**.

The second emission intensity average value is derived from values stored at the row specified by the wavelength stored in the corresponding line of the column **25***d* for wavelength **2** in the time line from start to the end of the etching process in the column **24***e* for emission intensity of the OES data table **24***a* of FIG. **6**. For example, the time line from start to the end of the etching process represents those from 1 to 100 shown in FIG. **6**.

In S**202-3**, the arithmetic unit **21** compares the first prediction error calculated in S**202-1** with the second prediction error calculated in S**202-2**, and stores the minimum value in the corresponding line of the column **25***g* for prediction error shown in FIG. **7**.

In S**202-4**, if the first prediction error is minimum, the arithmetic unit stores the information indicating the time interval from start to the intermediate stage of the etching process in the column **25***e* for wavelength **1**-time interval shown in FIG. **7**, and further stores the information indicating the time interval from start to the end of the etching process in the column **25***f* for wavelength **2**-time interval.

If the second prediction error is minimum, the information indicating the time interval from the intermediate stage to the end of the etching process is stored in the column **25***e* for wavelength **1**-time interval shown in FIG. **7**, and the information indicating the time interval from start to the end of the etching process is stored in the column **25***f* for wavelength **2**-time interval.

Since the element contained in plasma changes as the etching process proceeds, the plasma emission data will change depending on the first half and the second half of the etching process. By evaluating the prediction error in a classified manner into the first half and the second half of the time interval, it makes possible to specify the time interval suitable for prediction of the etching processing result.

In the above method, the time interval of the emission intensity of the wavelength of the divided part is separated into the first half and the second half. It is also possible to calculate the prediction error by separating the time interval into the first half and the second half with respect to the wavelength of the dividing part. The first half or the second half of the time interval may further be divided in detail to calculate the prediction error so as to use the resultant minimum value.

In S**203**, the arithmetic unit **21** calculates the standard deviation of time series change in the emission intensity for the respective combinations of wavelength stored in the lines of the initial search result data table **25***a* shown in FIG. **7**, and the resultant value is stored in the column **25***j* for standard deviation of emission intensity. The arithmetic unit **21** sequentially executes the process from the upper line of the initial search result data table **25***a*. The line to be processed will be referred to as the subject line.

In the column **24***e* for emission intensity of the OES data table **24***a* in FIG. **6**, the standard deviation of time series change in the emission intensity is calculated through the formula 6 with respect to data at the row specified by the wavelength stored in the subject line of the column **25***c* for wavelength **1** shown in FIG. **7**.

$$sd = \left\{\sum z_i^2 - \frac{\left(\sum z_i\right)^2}{m}\right\} \Big/ (m-1) \qquad \text{[Formula 6]}$$

Referring to the formula 6, the code z_i denotes the value stored in the ith line among those data pieces at the row specified by the wavelength stored in the subject line in the column **25***c* for wavelength **1** shown in FIG. **7**. The code m denotes the number of lines of the column **24***e* for emission intensity. The code E denotes the sum of data in all the lines of the column **24***e* for emission intensity. The sd value calculated through the formula 6 is one of values indicating the degree of time series change in the emission intensity.

FIGS. **14**A and **14**B show the respective time series changes in the emission intensity for each wavelength. A graph **1410** of FIG. **14**A has small time series change in emission intensity **1411**, and a small sd value. The wavelength of this type has small change in the average value of the emission intensity even if the time interval is changed. Accordingly, changing the time interval is not likely to improve the prediction error.

Meanwhile, a graph **1420** of FIG. **14**B has large time series change in emission intensity **1421** as well as a large sd value. The wavelength of this type has the average value of emission intensity which largely varies with change in the time interval. Accordingly, changing the time interval is likely to improve the prediction error. In the process of specifying the wavelength combination in S**204**, the wavelength combination is specified in consideration of the sd value.

The step S**203** calculates the sd value with respect to the wavelength stored in the column **25***c* for wavelength **1** shown in FIG. **7**. It is also possible to calculate the sd value with respect to the wavelength stored in the column **25***d* for wavelength **2**. It is further possible to obtain the sum or a weighted average of the sd value calculated with respect to the wavelength stored in the column **25***c* for wavelength **1** and the sd value calculated with respect to the wavelength stored in the column **25***d* for wavelength **2** so as to be stored in the column **25***j* for standard deviation of emission intensity.

In S**204**, the arithmetic unit **21** determines the specified wavelength combination for continuous search in the time interval using the value stored in the column **25***g* for prediction error and the value stored in the column **25***j* for standard deviation of emission intensity.

The arithmetic unit **21** ranks the prediction error sequentially from the smaller value in the line through calculation using the prediction error value stored in the column **25***g* for prediction error shown in FIG. **7**, and stores the rank in the respective lines of the column **25***h* for prediction error rank.

The arithmetic unit **21** ranks the prediction error sequentially from the smaller value in the line through calculation with respect to the line in which the value stored in the column **25***j* for standard deviation of emission intensity is smaller than the predetermined threshold value **1** (for example, 100), and stores the rank in the respective lines of the column **25***k* for prediction error rank **1**. Likewise, the arithmetic unit **21** ranks in the prediction error sequentially from the smaller value in the line through calculation with respect to the line in which the value stored in the column **25***j* for standard deviation of emission intensity is equal to or larger than the threshold value **1**, and stores the rank in the respective lines of the column **25***l* for prediction error rank **2**.

The arithmetic unit **21** stores the code ○ in the column **25***i* for continuous search so that the search is continuously performed in the time interval with respect to the line having the rank stored in the column **25***h* for prediction error rank, the column **25***k* for prediction error rank **1**, or the column **25***l* for prediction error rank **2** equal to or smaller than a predetermined threshold value **2** (for example, 10). The code – is stored in the column **25***i* for continuous search with respect to any other line.

The aforementioned process allows restriction of the wavelength combination for search in the time interval so as to reduce the search time.

In S**205**, the arithmetic unit **21** presents the information stored in the initial search result data table **25***a* to the operator so as to confirm whether or not the continuous search is required.

FIG. **15** shows an example of a screen of the output displayed by the arithmetic unit **21** for the operator. An output screen **1500** shown in FIG. **15** displays a list D**200** of combinations of wavelength and time interval, a scatter chart display section D**207**, and a continuous search instruction section D**208**.

The list D**200** of combinations of wavelength and time interval includes columns D**201** for prediction error rank, D**202** for wavelength **1**, D**203** for wavelength **2**, D**204** for wavelength **1**-time interval, D**205** for wavelength **2**-time interval, and D**206** for prediction error. Information data pieces respectively stored in the columns **25***h* for prediction error rank, **25***c* for wavelength **1**, **25***d* for wavelength **2**, **25***e* for wavelength **1**-time interval, **25***f* for wavelength **2**-time interval, and **25***g* for prediction error of the initial search result data table **25***a* shown in FIG. **7** are displayed from the first ranked line stored in the column **25***h* for prediction error rank in descending order.

The scatter chart display section D**207** displays a scatter chart **1510** showing the emission intensity monitor values and the etching processing results which are derived from calculating the emission intensity monitor values with respect to combination of wavelength and time interval with first ranked prediction error.

The continuous search instruction section D**208** displays the information for confirming the operator whether or not the continuous search is required. Pressing a button D**209** or D**210** allows the arithmetic unit **21** to advance the process to the next process step S**206**.

In S**206**, in response to pressing the button D**209**, that is, Yes in the continuous search instruction section D**208** by the operator, the process proceeds to the next step S**207**. Meanwhile, in response to pressing the button S**210**, that is, No, the first ranked data shown in FIG. **15** is stored in the control condition data storage unit **28** to end the analyzing process.

In S**207**, the arithmetic unit **21** evaluates the prediction error in the time interval divided in more detail than the case in step S**202** with respect to the wavelength combination that the code ○ indicating the continuous search is stored in the column **25***i* for continuous search of the initial search result data table **25***a* shown in FIG. **7**. The line to be processed will be referred to as the subject line. The detailed process flow in this step will be described referring to FIG. **10**C.

In this step, the process of calculating the prediction error with the emission intensity in the time interval which has been set using the random number (S**207-1**) is executed R times as the predetermined number of times (for example, 1000 times) (S**207-2**), the minimum value of the calculated prediction error values is stored in the subject line of the column **26***g* for prediction error of the random number search result data table **26***a* shown in FIG. **8** (S**207-3**), and the time interval for providing the minimum value is stored in the columns **26***e* for wavelength **1**-time interval and **26***f* for wavelength **2**-time interval (S**207-4**). The combination of the wavelength for search and its ID are stored in the columns **26***b* for ID, **26***c* for wavelength **1**, and **26***d* for wavelength **2** (S**207-5**).

The arithmetic unit **21** repeats the process of calculating the prediction error (S**207-1**) R times to obtain R prediction errors in the different time intervals. The detailed procedure in the process of calculating the prediction error (S**207-1**) will be described referring to FIG. **10**D. In the process of calculating the prediction error (S**207-1**), the emission intensity monitor value data table **29***a* shown in FIG. **11** is generated like the process in S**202** to calculate the prediction error value through the formulae 1 to 5.

The column **29***b* for wafer ID of the emission intensity monitor value data table **29***a* shown in FIG. **11** stores the information indicating the wafer with acquired data, for example, the information stored in the column **23***b* for wafer ID of the etching processing result table **23***a* shown in FIG. **5**.

The arithmetic unit **21** selects two points using the uniform random number from those in the time interval (in the example shown in FIG. **6**, from 1 to 100) in the column **24***d* for time, which are stored in the OES data table **24***a* shown in FIG. **6** (S**207-1-2**). The small value and the large value of those of the selected time are set to TS**1** and TE**1**, respectively (S**207-1-3**). The arithmetic unit **21** calculates the third emission intensity average value of those stored at the row specified by the wavelength stored in the corresponding line of the column **25***c* for wavelength **1** shown in FIG. **7** in the time line from TS**1** to TE**1** of the column **24***e* for emission intensity of the OES data table **24***a* of FIG. **6** (S**207-1-4**).

The arithmetic unit **21** selects two points using the uniform random number of time stored in the OES data table **24***a* (S**207-1-5**). The small value and the large value among the selected time values are set to TS**2** and TE**2**, respectively (S**207-1-6**). The arithmetic unit **21** calculates the fourth emission intensity average value of those stored at the row specified by the wavelength stored in the corresponding line of the column **25***d* for wavelength **2** shown in FIG. **7** in the time line from TS**2** to TE**2** of the column **24***c* for emission intensity of the OES data table **24***a* of FIG. **6** (S**207-1-7**).

The column **29***c* for emission intensity monitor value shown in FIG. **11** stores the value obtained by dividing the third emission intensity average value by the fourth emission intensity average value (S**207-1-8**) as described below.

The column **29***d* for etching processing result of the emission intensity monitor value data table **29***a* stores the value stored in the column **23***c* for etching processing result of the etching processing result table **23***a* shown in FIG. **5** so as to be corresponded to the wafer ID (S**207-1-9**).

The arithmetic unit **21** calculates the prediction error (e) for prediction of the etching processing result using the emission intensity monitor value through the aforementioned formulae 1 to 5 (S**207-1-10**). The calculated prediction error (e) becomes the one to be obtained in S**207**.

The arithmetic unit **21** stores the minimum value of prediction errors calculated R times in the subject line of the column **26***g* for prediction error of the random number search result data table **26***a* shown in FIG. **8** in S**207-3**, and stores the time interval providing the minimum value in the columns **26***e* for wavelength **1**-time interval and **26***f* for wavelength **2**-time interval in S**207-4**. The wavelength combination determined to be searched in S**207-5** and the corresponding ID are stored in the columns **26***b* for ID, **26***c* for wavelength **26***c*, and **26***d* for wavelength **2**, respectively.

In S**208**, the arithmetic unit **21** calculates the rank of the prediction error values from the line of smaller value so as to be stored in the respective lines of the column **26***h* for prediction error rank using the prediction error value stored in the column **26***g* for prediction error of the random search result data table **26***a* shown in FIG. **8** The arithmetic unit **21** specifies the line with the lowest rank stored in the column **26***h* for prediction error rank, stores the code ○ in the column **26***i* for continuous search so that the search in the time interval is continued in the subject line, and further stores the code – with respect to any other line in the column **26***i* for continuous search. In this example, only one line is specified. However, it is possible to specify a plurality of lines in the order of smaller prediction error with the code ○ for continuous search.

The aforementioned process makes it possible to restrict the wavelength combination for search in the time interval, thus reducing the search time.

In S**209**, the arithmetic unit **21** specifies the line that stores the code ○ indicating the continuous search in the column **26***i* for continuous search of the random number search result data table **26***a* shown in FIG. **8**, reads the information stored in the subject line of the columns **26***b* for ID, **26***c* for wavelength **1** and **26***d* for wavelength **2**, and stores the read information in the columns **27***b* for ID, **27***c* for wavelength **1**, and **27***d* for wavelength **2** of the final search result data table **27***a* shown in FIG. **9**.

The arithmetic unit **21** further calculates the emission intensity monitor value with respect to combination of all the possible time intervals with the wavelength stored in the columns **27***c* for wavelength **1** and **27***d* for wavelength **2**, and calculates the prediction error (e) with respect to the emission intensity monitor values through the formulae 1 to 5. Among the calculated values of prediction error (e), the minimum value is stored in the column **27***g* for prediction error of the final search result data table **27***a*, and the time interval providing the minimum value is stored in the columns **27***e* for wavelength **1**-time interval and **27***f* for wavelength **2**-time interval.

If the code ○ indicating the continuous search is stored in a plurality of lines of the column **26***i* for continuous search, the prediction error (e) is calculated with respect to the combinations of all possible time intervals with the wavelength values in the respective lines. Among combinations of the respective wavelength values and time intervals, the combination of wavelength and time interval, which exhibits the minimum prediction error, and the corresponding ID are stored in the final search result data table **27***a*.

In S**210**, the arithmetic unit **21** outputs the values stored in the final search result data table **27***a* shown in FIG. **9** and data relevant to the scatter chart on the screen as the final search results to end the process. FIG. **16** shows an example of the output screen presented by the arithmetic unit **21** to the operator.

The output screen shown in FIG. **16** displays a table D**300** of combination of wavelength and time interval, which exhibits the first ranked prediction error, and a scatter chart display section D**307**.

A column D**301** for prediction error rank of the table D**300** of wavelength and time interval which exhibits the first ranked prediction error stores the number **1** indicating that the value with the minimum prediction error among those of the searched wavelength and time interval. The columns D**302** for wavelength **1**, D**303** for wavelength **2**, D**304** for wavelength **1**-time interval, D**305** for wavelength **2**-time interval, and D**306** for prediction error are displayed so as to display information stored in the columns **27***c* for wavelength **1**, **27***d* for wavelength **2**, **27***e* for wavelength **1**-time interval, **27***f* for wavelength **2**-time interval, and **27***g* for prediction error.

The scatter chart display section D**307** displays the scatter chart **1610** of the emission intensity monitor values and the etching processing result upon calculation of the emission intensity monitor value with respect to the combination of wavelength and time interval, which exhibits the first ranked prediction error.

The operator is allowed to identify the combination of wavelength and time interval which exhibits small prediction error of the etching processing result by confirming the output screen shown in FIG. **16**.

The content displayed on the output screen which has been stored in the final search result data table **27***a* shown in FIG. **16** is stored in the control condition data storage region **28** of the storage unit **22** shown in FIG. **1**.

In mass production, the data stored in the control condition data storage region **28** is used to control the plasma processing unit **11** with the control unit **13** for sequentially etching the wafer **114**.

As described above, use of the analyzing method performed by the etching apparatus **1** (analyzing section **20**) according to the present embodiment makes it possible to easily identify the combination of wavelength and time interval which exhibits the small prediction error of the etching processing result, from a plurality of combinations of wavelength and time interval.

The embodiment allows adequate determination of a plurality of conditions of measurement wavelength and measurement time as the plasma emission monitor condition. This makes it possible to execute the etching process highly accurately by maintaining the suitable flow rate of the etching processing gas.

The embodiment allows adequate determination of a plurality of conditions of measurement wavelength and measurement time as the plasma emission monitor condition. This makes it possible to provide the prediction value of the etching processing result with high accuracy while reducing the error compared with the related art.

As a result, it is possible to calculate the difference between the target value and the prediction value of the etching processing result with higher accuracy. The etching process is executed while accurately controlling the adjustment value of the etching processing condition, for example, the flow rate of the etching gas (gas flow rate) supplied from the gas supplier **117** so as to ensure formation of the fine shape pattern in the stable state.

The present invention has been described based on the present embodiment in detail. However, it is to be understood that the invention is not limited to the present embodiment as described above, and may be variously modified so long as it does not deviate from the scope of the invention.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiment is therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims, rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed is:

1. An etching apparatus comprising:

a processing chamber;

a plasma generating unit for generating plasma by introducing etching gas into the processing chamber exhausted in vacuum, in which a specimen is disposed;

a plasma emission monitor unit for monitoring emission of the plasma generated by the plasma generating unit;

an arithmetic unit for generating data concerning a condition of controlling the plasma generating unit;

a storage unit for storing the data concerning a condition of controlling the plasma generating unit, which has been generated by the arithmetic unit; and

a control unit for controlling the plasma generating unit based on a state of the plasma emission monitored by the plasma emission monitor unit and the control data stored in the storage unit,

wherein the arithmetic unit generates a wavelength combination from wavelength band of the plasma emission to be generated upon etching of the specimen as a condition for etching the specimen by the plasma generating unit, sets a time interval for calculating an average value of emission intensity in a time period for etching the specimen with respect to the generated wavelength combination, calculates a prediction error for prediction of the etching processing result using the average value of the emission intensity in the time interval with respect to each of the generated wavelength combinations, specifies a combination of wavelength and time interval, which exhibits a minimum value of the calculated prediction error, and generates a condition for etching the specimen using a prediction value of the etching processing result with respect to the combination of wavelength and time interval, which exhibits the minimum value of the specified prediction error.

2. The etching apparatus according to claim **1**, wherein the arithmetic: unit specifies the wavelength combination from the calculated prediction error, calculates a second prediction error by searching the time interval with respect to the specified wavelength combination, and selects the combination of wavelength and time interval, which exhibits a minimum value of the second prediction error, as the wavelength and the time interval used for predicting the etching processing result.

3. The etching apparatus according to claim **1**, further comprising an output section which outputs information concerning the combination of wavelength and time interval, which exhibits the minimum value of the prediction error selected, as the wavelength and the time interval for predicting the etching processing result by the arithmetic unit together with information of the prediction error.

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